The Next Generation 3GeV Synchrotron Radiation Facility Project in Japan

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ABSTRACT

Advanced synchrotron radiation (SR) has been recognized as a premier research tool for developments of science and technology as well as for core industrial applications. Large-scale SR facilities around the world are constantly evolving, providing super brilliant and super directive X-rays. Consequently, a new range of applications in the nano-disciplines has been created.

Since 2012, we have been pursuing a low emittance 3 GeV synchrotron radiation facility project: SLiT-J (Synchrotron Light in Tohoku, Japan). After extended deliberations, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan decided to initiate construction of the new 3 GeV facility on the campus of Tohoku University. The construction and operation of the facility will be carried out by a new organization. It is a combined public–private regional partnership, in which the partners are the National Institute of Quantum Radiological Science & Technology (QST), Tohoku University, Miyagi Prefecture, Sendai-City; the Tohoku Economic Federation; and the Photon Science Innovation Center. Funding comes from private sector investments, local governments, and MEXT through QST.

The primary target of the project is to drive innovation by pioneering nanometer scale visualization of materials' function as a "Super Light Source for Industrial Technology (SLIT-J)". A groundbreaking concept, utilizing an industry-academic alliance for SR applications, called the "Coalition Concept", is also arising out of the dialogue with industries and professors about the outlook for the research market of SLIT-J.

INTRODUCTION

Following the Great East Japan Earthquake in 2011, the national government embarked on extensive development work in the region, including SLiT-J (Synchrotron Light in Tohoku, Japan). Plans for this new 3 GeV synchrotron radiation (SR) facility sparked discussion about the great demand for next-generation low emittance SR rings from the perspective of industrial science and technology. The SLiT-J project intends to build a "super light source for industrial technology in Japan (SLIT-J)". Achieving this vision has required designs for the light source, concepts for the end-stations (the experimental facilities), and a groundbreaking "Coalition Concept" for an industry-academic alliance for SR applications. In December 2018, the national government gave the green light to the project as a "Next Generation 3GeV SR Facility" project based on the public and private sectors' regional partnership. In order to complete the project, the National Institutes for Quantum and Radiological Science and Technology (QST) was assigned as the main body with the following partners; Miyagi Prefecture, Sendai City; the Tohoku Economic Federation; Tohoku

University; and the Photon Science Innovation Center (PhoSIC)[1]. The facility is planned to be built at the new Aoba-yama campus of Tohoku University, which is 7 minutes, by subway, from Sendai station.

Fig. 1: A rendering of the next generation 3GeV SR facility at Tohoku University's Aoba-yama Campus.

LIGHT SOURCE

Nanoscopic science and industrial R&D need a brilliant and high coherence light source covering the energy levels of the outer-shell electrons in major elements (i.e., X-rays with energy levels ranging from 50 eV to 30 keV). To meet this demand, the light source has been designed as a low-emittance 3 GeV synchrotron storage ring using state-of-the-art accelerator technology that is available in Japan. The initial design of the storage ring was made based on the double-double bend achromat [2]. The final design of the storage ring consists of 16 cells of a 4-bend achromat lattice, in which each cell has 4 bending magnets (Fig.2, Table I). The facility is designed to save energy by making the devices and equipment as compact as possible.

END STATIONS

A maximum of 26 beam lines can be installed in the storage ring. 7 to 10 beam lines will be available when the facility is opened, and additional beam lines will be installed to meet scientific demands. End-stations (ESs), will be categorized into two types: automated measurement stations and advanced measurement stations. The automated measurement stations will enable high-throughput routine measurements by making full use of robot and IT technology along with the brilliant X-rays. The advanced measurement stations will enable users to make customized measurements under various conditions and environments by installing their own custom-developed instruments into the station using a standardized plug-in system (Fig. 3). Furthermore, the plug-in system will allow users to perform measurements utilizing multi-beam lines.

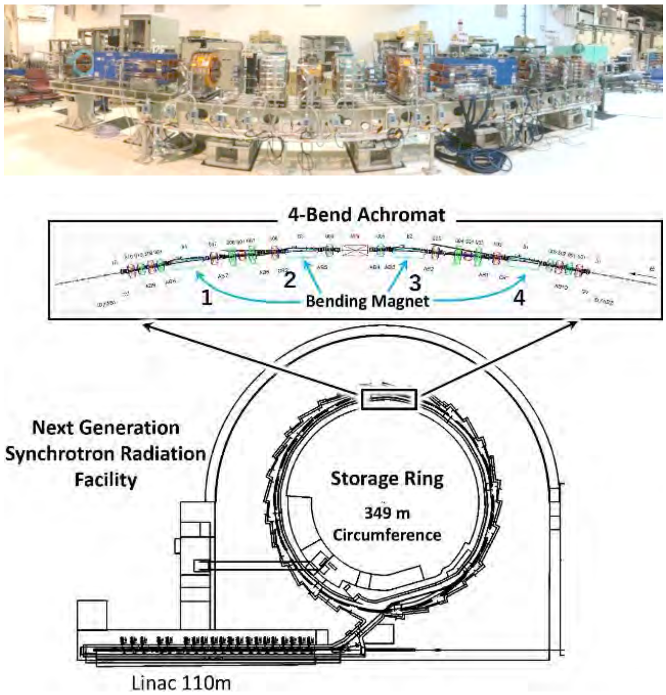

Fig. 2: Blueprints of the facility.

Lattice parameter		
Beam energy	E (GeV)	2.998
Lattice structure		4bend achromat
Circumference	C (m)	348.8432
Number of cells	N_s	16
Long straight section	(m)	5.4400 × 16
Short straight section	(m)	1.6427 × 16
Betatron tune	x / y	28.17 / 9.23
Natural chromaticity	x / y	-60.50 / -40.99
Natural horizontal emittance	(nmrad)	1.14
Momentum compaction factor	α	0.000433
Natural energy spread	$\sigma E/E$ (%)	0.0843
Lattice functions at LSS	$\beta_x / \beta_y / \eta_x$ (m)	13.0 / 3.0 / 0.0
Lattice functions at SSS	$\beta_x / \beta_y / \eta_x$ (m)	4.08 / 2.962 / 0.052
Damping partition number	J_x / J_s	1.389 / 1.611
Damping time	$\tau_x / \tau_y / \tau_s$ (ms)	8.091 / 11.238 / 6.976
Energy loss in bends	(MeV/turn)	0.621
RF frequency	(MHz)	508.75905
Harmonic number	h	592
Beam size at long straight	σ_x/σ_y	121/5.8

Table I: Main parameters of the light source.

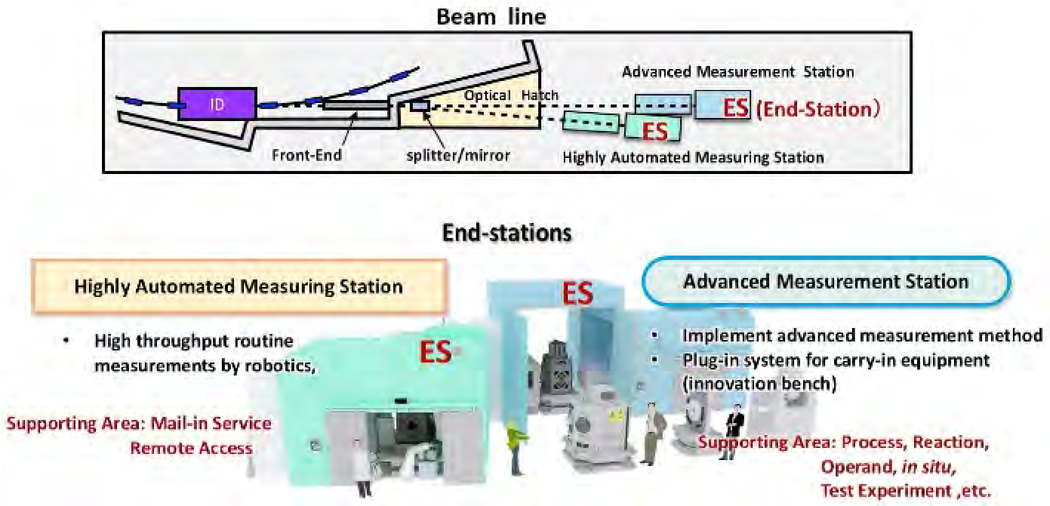

Fig. 3: Schematic view of the beamline and end-station.

The first ten beamline lineups have been suggested by the QST/PhoSIC Beamline Design Committee to envision the following concept:

(1) effective use of the low-emittance light source;
(2) the needs of academia and industries; and
(3) complementarity in utilization of existing facilities in Japan.

Four out of the ten beamlines will allow access to highly brilliant tender X-rays from 2 to 5keV or higher for the purpose of X-ray coherent diffraction imaging and X-ray operando spectroscopy. The rest are soft-X-ray beamlines covering an energy range from 50 eV to 2 keV, devoted to various spectroscopy experiments. The brilliance and photon flux in this energy range are expected to be 10-100 times as high as those available at SPring-8.

BL Number	BL name	Planned experiments	Insertion device	Energy range (polarization)	Energy resolution	Beam size
BL-I	X-ray operando spectroscopy	· Ambient-pressure X-ray photoelectron spectroscopy · Ambient-pressure X-ray absorption fine structure spectroscopy · X-ray diffraction	In-vacuum plane undulator	2-20 keV (horizontal linear polarization)	E/△E= 7,000	100 nm
BL-II	X-ray structural and electronic-state total analysis	· Scanning transmission X-ray microscopy · Small-angle/wide-angle X-ray scattering · X-ray absorption fine structure spectroscopy	Multipole wiggler	2-20 keV (horizontal linear polarization)	E/△E= 7,000	50 μm
BL-III	X-ray multiscale structure analysis	· X-ray absorption, imaging · Phase contrast imaging · Scanning X-ray fluorescence imaging · X-ray diffraction · X-ray fluorescence holography	Multipole wiggler	4.4-30 keV (horizontal linear polarization)	E/△E= 7,000	50 μm
BL-IV	X-ray coherent imaging	· Coherent X-ray diffraction imaging · X-ray ptychography · Ptychography X-ray absorption fine structure spectroscopy	In-vacuum plane undulator	3.1-20 keV (circular polarization) 2-20 keV (horizontal linearpolarization) 3.1-20 keV (vertical linear polarization)	E/△E= 7,000	50μm (unfocused) 100 nm (focused)
BL-V	Soft X-ray magnetic imaging	· Soft X-ray phase-contrast imaging · Scanning transmission imaging · Scanning X-ray fluorescence imaging · Soft X-ray magnetic imaging · X-ray magnetic circular dichroism · X-ray magnetic linear dichroism · X-ray magneto-optical Kerr effect	APPLE undulator	0.18-1.2 keV (circular polarization) 0.13-2 keV (horizontal linear polarization) 0.23-2 keV (vertical linear polarization)	E/△E= 10,000-30,000	< 50 nm
BL-VI	Soft X-ray electronic state analysis	· Nanoscale photoemission spectroscopy · Resonant Inelastic X-ray scattering	APPLE undulator	0.05-1.0 keV (horizontal linear polarization) 0.05-1.0 keV (vertical linear polarization)	E/△E= 10,000-30,000	< 50 nm
BL-VII	Soft X-ray operando spectroscopy	· Near ambient pressure X-ray photoemission spectroscopy · Near ambient pressure X-ray absorption fine structure spectroscopy	APPLE undulator	0.13-2 keV (horizontal linear polarization) 0.23-2 keV (vertical linear polarization)	E/△E= 10,000-30,000	< 50 nm
BL-VIII	Soft X-ray nanoscale photoemission spectroscopy	· Nanoscale spin-resolved angle-resolved photoemission spectroscopy	APPLE undulator	0.05-1.0 keV (circular polarization) 0.05-1.0 keV (horizontal linear polarization) 0.05-1.0 keV (vertical linear polarization)	E/△E= 10,000-30,000	50nm-10μm
BL-IX	Soft X-ray nanoscale absorption spectroscopy	· X-ray magnetic circular dichroism · X-ray magnetic linear dichroism · X-ray magneto-optical Kerr effect · X-ray linear dichroism · X-ray ferromagnetic resonance spectroscopy	Segmented APPLE undulator	0.18-2 keV (circular polarization) 0.13-2 keV (horizontal linear polarization) 0.18-2keV (vertical linear polarization)	E/△E >10,000	50nm-10μm
BL-X	Soft X-ray superhigh-resolution resonant inelastic scattering	· Superhigh-resolution resonant inelastic X-ray scattering	APPLE undulator	0.25-1.0 keV (circular polarization) 0.25-1.0 keV (horizontal linear polarization) 0.25-1.0 keV (vertical linear polarization)	E/△E >150,000	< 500 nm

Table II: The list of planned beam lines.

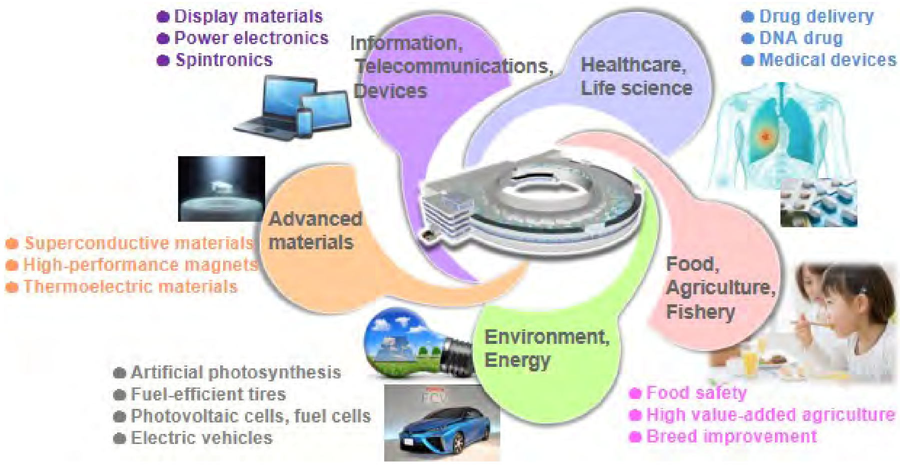

Fig. 4: Diverse applications of SLIT-J.

DRIVE INNOVATION

The light source performance of the next generation SR facility will exceed that of all soft X-ray facilities in Japan. This facility will be a critical tool to visualize materials' functions and to establish an industry-academic alliance for SR applications under a new regime, the "Coalition Concept".

Universities and companies will establish their R&D site close to the new, next-generation SR facility to drive research outputs to commercial outcomes by utilization of the world's most advanced light, which leads to the formation of a "Science Park"(Fig.1). The economic effect of the science park is estimated to be 1.9 trillion yen in a 10-year period. We intend to transform the science park into a world-renowned hub for value creation coupled with the university's human resource development programs. Our goal is to build a research complex that contributes to sustainable national growth in science, technology, economy and society.

NEW REGIME OF INDUSTRY APPLICATIONS

A key objective of SLIT-J (Super Lightsource for Industrial Technology, Japan) is to promote interdisciplinary alignment between industry R&D applications and academic research applications. Industrial users require a practical and demand-oriented user-support system staffed with relevant experts. At the same time, competition for resources among the industrial companies must be managed. The Coalition Concept is a new approach where academic researchers provide one-on-one collaborative support for a company that is providing funding for construction of SLIT-J.

The academic coalition partners will support the SR research of their industrial partners by sharing R&D objectives for SR experiments and assisting it with data analysis. The industry's main concerns with this scheme are preventing technology leaks and protecting industrial technology. The key to addressing these risks is to implement a demarcation line separating the "cooperative zone" from the "competitive zone" for SR usage. An alternative solution would be to systemize analysis companies as coalition partners. This "Coalition Concept" has been attracting industrial users for advanced utilization of the SR facility, which, we believe, will lead to solving the essential problems of industries and will promote the diversity of SR research.

The Coalition Concept is intended to be an engine to drive the business ecosystem for sustainable growth. We anticipate that a positive spiral will be created in the business ecosystem; excellent strategies and research results are recognized by society, which then attracts talented researchers' attention to gather at the university or the science park. Together with these new participants, the host community will build an advanced strategy supported by their knowledge and human resources.
The Coalition Concept shall support the research complex that we envision: the "research conducting community".

The site preparation work started in March of 2019, and the first beam is scheduled in 2023.

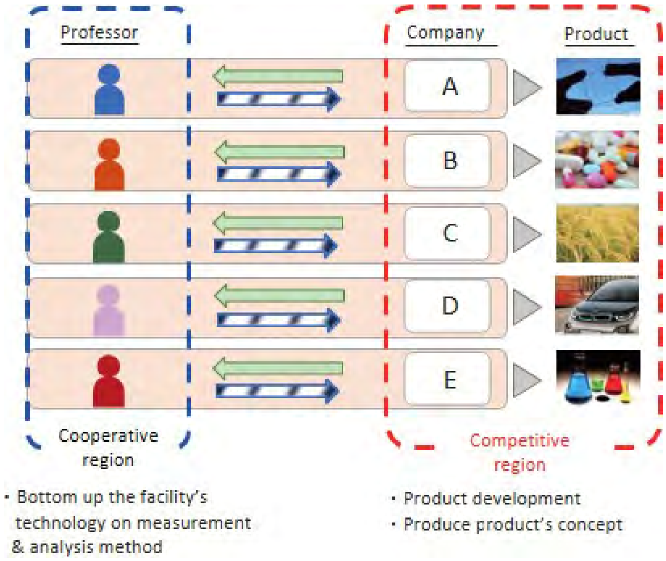

Fig. 5: Coalition Concept: a new industry-academic alliance scheme.

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